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Thesis
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#14

THE UNIVERSITY OF ALBERTA

"Ultra Violet Dispersion of Air"

A DISSERTATION
SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES
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OF MASTER OF SCIENCE

FACULTY OF ARTS AND SCIENCE
DEPARTMENT OF PHYSICS

by
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Edmonton, Alberta,

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Abstract

The relative refractive index of air was measured at eight wavelengths, from 5852 to 2536 A, using a Fabry-Perot interferometer. Using these values a least squares dispersion equation, of the Cauchy type, was calculated. This equation was adjusted to give a best fit with the values given by Barrell and Sears for the visible region. The resulting dispersion equation, for standard air, is compared with the dispersion equations derived by Barrell and Sears, Meggers and Peters, and Edlén.

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I INTRODUCTION

During the last twenty-five years it has become increasingly apparent that the dispersion formula for air, found by Meggers and Peters[1], and almost universally used by spectroscopists, is too large in the ultra violet,[2,3] by nearly one percent at 2000 A. There is also some indication, from measurements made in 1934 by Kösters and Lampe[4] and by Pérard[5], and in 1939 by Barrell and Sears[6], that Meggers and Peters' values may be too low in the visible. The measurements made in 1934 and 1939 should, judging from the different methods of observation and the substantial agreement between the results, be fairly accurate for the visible region where the observations were made.

The discrepancy between Meggers and Peters' values and the more recent determinations of the refractive index is between 50 and 100×10^{-8} in the visible region. This may not be very large but as wavelength measurements are now being made to the order of one part in fifty million it is necessary that the refractive index be known to the same precision, that is about 2×10^{-8}. Meggers[3] has noted the error in the dispersion for the ultra violet but has made no mention of the visible.

Newbound[7] has suggested that the change in etalon thickness due to the gas pressure compressing the etalon spacers (and other parts of the interferometer) may be much

greater than that calculated from the bulk modul~~a~~us and that this may account for the error in Meggers and Peters work. No attempt has been made to check this theory, in the present work.

In the present work the index of refraction of air was determined on a relative basis for seven lines of ${}^{198}_{80}\mathrm{Hg}$ using a Fabry-Perot interferometer crossed with a Hilger El Littrow spectrograph, with quartz optics. Measurements were made in dry, carbon-dioxide-free air and in vacuum using the neon secondary standard lines. Neon was chosen because:

1) it is much simpler to use several secondary standards than the primary standard alone, and

2) the neon spectrum is easily produced experimentally.

II THEORY

The theory of the Fabry-Perot interferometer is well known and has been adequately covered elsewhere, e.g. Tolansky[8] or Meissner[9], therefore only the material necessary for the calculation of the refractive index will be considered.

1. Calculation of the Fractional Order of Interference, e,

For constructive interference the fundamental equation of interference is

$$P\lambda = 2t\cos\theta \tag{1}$$

where P is an integer, λ is the wavelength, t is the etalon thickness, θ is the angle which the light makes with the normal to the reflecting films. The fringes are at infinity and are brought to a focus by a suitable lens. These fringes consist of alternate bright and dark rings.

The bright rings in the interference pattern are numbered 0, 1, 2, -- starting from the center. For the center of the pattern we can write

$$(p+e)\lambda = 2t \tag{2}$$

where p is an integer and e is the fractional order of interference and may be determined by a reduction of the fringe pattern. If D_n is the diameter of the nth bright

fringe, then

$$D_n^2 = (n + e_n)\Delta D^2 \tag{3}$$

where ΔD^2 is a constant for a given pattern.

It is generally desirable to average the e's calculated from a number, n, of fringe diameters, usually 3 to 6. This can be very conveniently accomplished, for five fringe diameters, by the method of least squares (cf. Appendix I). The normal equations can be written in the form

$$K \sum_n D_n^2 = \sum_n n + je \tag{4}$$

$$K \sum_n n D_n^2 = \sum_n n^2 + e \sum_n n \tag{5}$$

where $K = \Delta D^{-2}$ and all the summations are from $n = 0$ to $n = j - 1$, j being the number of fringe diameters observed. Putting $j = 5$ and solving for e we find,

$$e = \frac{3 \sum D_n^2 - \sum n D_n^2}{\frac{1}{2} \sum n D_n^2 - \sum D_n^2} \tag{6}$$

The individual e_n's may be calculated, using

$$e_n = \frac{D_n^2}{\Delta D^2} - n \tag{7}$$

where

$$\Delta D^2 = \frac{1}{5}\left(\frac{1}{2} \sum n D_n^2 - \sum D_n^2\right)$$

An estimate of the probable error can then be made by the usual treatment of residuals.

$$\text{probable error in } e = 0.6745\left(\frac{\sum(e_n - e)^2}{n(n-1)}\right)^{1/2} \qquad (8)$$

2. Determination of Exact Thickness

The determination of the exact etalon thickness, t, which is necessary to compute the wavelengths and hence the index of refraction, requires a knowledge of

a) the fractional parts for at least two standard wavelengths

b) an approximate value for the etalon thickness.

The exact thickness may be found in several ways (Meissner[8]) but the following method was used due to the availability of two Marchant computing machines. An approximate order number P for the standard lines was found using the approximate thickness and equation (2). A standard wavelength was set in the keyboard of each machine as multiplicand, while the corresponding approximate order number with the measured value of e was used as a multiplier. This multiplication gives, by equation (2), an approximate value of 2t, which will be different for the two standards. The approximate order numbers were then varied by units (which can be done without disturbing the fractional parts) until agreement within 2 or 3 parts in 10^8 is reached for the value of 2t. A third standard is then used to check this value. Once the exact thickness, 2t, has been found for one

exposure, those following are much easier to determine as the variation in 2t is small if the etalon is not disturbed.

3. Theory of Refractive Index

The general dispersion equation developed by Lorentz[12] can be written, for a given medium, in the form

$$\frac{n^2-1}{n^2+2} = \sum \frac{D_0'}{V_0^2 - V^2} \tag{9}$$

where the D_0' terms of the series are constants, v is the frequency of the incident radiation and the v_0 terms are the frequencies of the lines in the absorption spectrum of the dispersing medium. For a wavelength region well removed from the absorption bands of air in the extreme ultra violet, (9) may be expanded, on the right, in a Cauchy form

$$\frac{n^2-1}{n^2+2} = a_0' + a_2'\lambda^{-2} + a_4'\lambda^{-4} + \cdots \tag{10}$$

When n differs only slightly from unity the left hand side reduces to n-1 and (10) becomes

$$(n-1) = a_0 + a_2\lambda^{-2} + a_4\lambda^{-4} + \cdots \tag{11}$$

which has been found to give a satisfactory expression for the dispersion of air.

4. Calculation of Index of Refraction

The determination of the refractive index requires that at least two interferograms, of each radiation, be

observed; one when the interferometer is in a vacuum, and the second when the substance under examination is between the interferometer plates. Two equations of the form (2) are then applicable

$$(p+e)\lambda = 2t$$
$$(p'+e')\lambda' = 2t \qquad (12)$$

where the unprimed values refer to the vacuum and the primed values refer to the substance.

Using (12), in conjunction with the definition of refractive index gives,

$$n = \frac{\lambda}{\lambda'} = \frac{(p'+e')}{(p+e)} \qquad (13)$$

then

$$(n-1) = \frac{p'-p+e'-e}{p+e}$$

$$\text{let } x = p'-p$$

$$(n-1) = \frac{x+e'-e}{p+e} \qquad (14)$$

Where the densities are small x will be zero or some small integer which is readily determined from an approximate value of (n - 1). Since p is not required to high precision we may use the first of equations (12) to obtain,

$$(n-1) = \frac{\lambda(x+e'-e)}{2t} \qquad (15)$$

Thus to calculate the refractive indices we need to know:

a) the fractional parts e for the wavelengths for which the refractive indices are desired

b) the approximate value of the wavelengths in (a), that is to six significant figures

c) the thickness, 2t, to at least six figures

d) an approximate value of $(n - 1) \times 10^6$ (2 figures)

5. Phase Change on Reflection

Metallic surfaces have an index of refraction which is a complex quantity, both the real and imaginary parts of which are, in general, functions of wavelength. Hence it is usually necessary to make a small correction, to the refractive index calculated by (15), due to the slightly different wavelengths in vacuum and in the substance. The change in phase causes the etalon to appear to have a slightly different thickness in the two cases[10].

Let d(2t) be this apparent change in thickness and assume that it appears when the substance under examination is between the plates. Then the second of equations (12) becomes

$$(p'+e')\lambda' = 2t + d(2t) \tag{16}$$

while the first remains unchanged. Then proceeding as in section 4, we find

$$n = \frac{\lambda}{\lambda'} = \frac{p'+e'}{p+e} - \frac{d(2t)}{2t}$$

and

$$(n-1) = \frac{\lambda(x+e'-e)}{2t} - \frac{d(2t)}{2t} \tag{17}$$

However the refractive index of air is close to unity ~~small~~ and thus the change in wavelength from air to vacuum is small. This means that the effect in 2t due to phase effect is small, usually in the eighth figure, and as 2t is needed here to at the most seven figures the effect of phase change on reflection may be neglected.

III APPARATUS

1. General

The apparatus described by Smith[13] was modified slightly by installing a mercury vapour pump near the etalon chamber and moving the mechanical vacuum pump to the corner of the room about five meters away and connecting them together by ten meters of fourteen millimeter pyrex tubing. Vibration mounts (three sets) were installed under the mechanical vacuum pump, also, vibration mounts were placed under the fan and under the stirring motor. This arrangement reduced the vibration to such a level that there was no noticeable effect on the surface of a beaker of mercury when the apparatus was operating.

The long glass vacuum line between the mechanical vacuum pump and the rest of the apparatus did not appreciably reduce the pumping speed and with the mechanical pump alone the vacuum was at least as high as it was when the pump was connected by a few feet of rubber tubing. This arrangement allowed continuous pumping, which was an absolute necessity due to the long exposures required, and gave a vacuum in the manometer of the order of 10^{-5} millimeters of mercury and in the etalon chamber of the order of $5x10^{-3}$ millimeters of mercury.

Some inconsistencies were discovered in the MacLeod

gauge used by Smith[13] and a new, all glass, MacLeod gauge was constructed (calibration, Appendix II). This was connected to the etalon chamber and the manometer by Butyl rubber tubing, Butyl being used to reduce the effect of air diffusing through the rubber. (Butyl has approximately one-tenth the diffusivity of natural rubber).

Other than these, the light source and its excitation, and the spectrograph settings (see Appendix III) no other changes were made in the apparatus described by Smith[13], hence the details will be omitted here.

2. Light Sources and Excitation

A lamp holder was designed and built which permitted either the neon standard or the mercury 198 lamp to be slipped rapidly into position in front of the etalon. Unfortunately it became necessary to remove the mercury 198 lamp and when it was replaced it was found to be slightly out of position. Rather than try to find the proper position once more the alignment of the lamps was checked by observing the image formed on the mask in front of the spectrograph lens. The position of the light source is not critical according to Tolansky[8] and thus this alignment was sufficiently accurate.

The neon standard was an ordinary capillary type Geissler tube. The 600 megacycle oscillator would not oper-

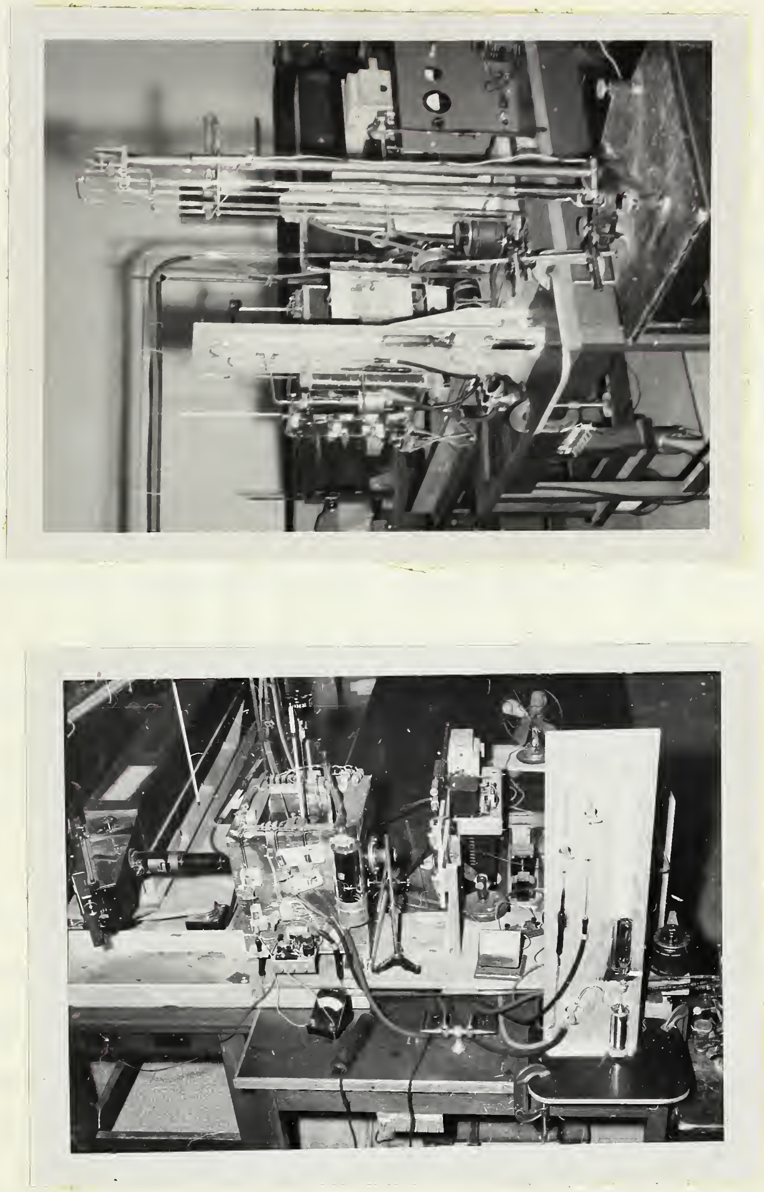


PLATE I General View of Apparatus.

ate this tube successfully and it was necessary to use 60 cycle alternating current stepped up by a high voltage transformer, the primary of which was connected to a variac. A bridge-type copper oxide rectifier was placed in the high voltage circuit with a direct current milliammeter in the center of the bridge. (This was found to be more satisfactory than using an alternating current milliammeter). This allowed easy measurement of the current in the neon lamp. It was found that the neon lamp became unstable for currents of approximately 6 milliamperes dc., hence the neon lamp was operated at 7 milliamperes dc. for all exposures.

The mercury 198 lamp, of vycor glass, was obtained from Baird Associates, Cambridge, Massachusetts, and contains a few milligrams of artificially prepared $^{198}_{80}$Hg and a trace of $^{199}_{80}$Hg.

Meggers[14] has claimed that no evidence of cleanup was observed for excitation frequencies higher than 300 megacycles. A 600 megacycle war surplus radar transmitter ~~was~~ is used to excite the mercury 198 lamp. This oscillator ~~which~~ has two triode push-pull, tuned plate - tuned cathode (resonant lines) oscillators (see for instance 15) working in parallel and indications of cleanup were noticeable after approximately eighteen hours of operation. For this reason the lamp was removed from the lamp holder and wrapped in aluminum foil, except for the interelectrode space. The

darkening due to cleanup was observed only near the outer edge of the electrodes (that is, towards the ends of the tube) and as Tolansky[8] has reported that no cleanup occurs under the electrodes it was decided to wrap the ends of the mercury lamp in aluminum foil thus placing all the lamp except the interelectrode space under the electrodes and thereby preventing cleanup.

No attempt was made to measure the power delivered by the ultra high frequency oscillator (UHF) but judging from the intensity of the lamp and the length of exposures needed there could not have been more than five watts delivered to the lamp. With this low power it does not seem possible that the cleanup observed could be due to a low frequency produced by the two oscillators being slightly different and thus producing a beat frequency.

3. The Densitometer

The Photomultiplier circuit as used by Smith[13] was modified slightly to provide better selectivity and control. The modified circuit is given below:

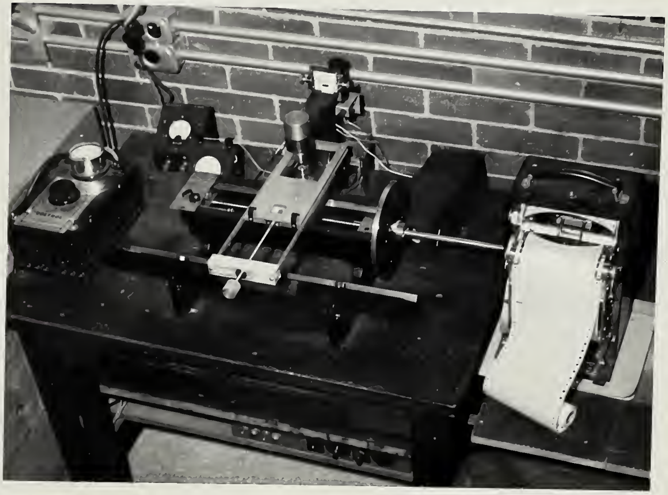
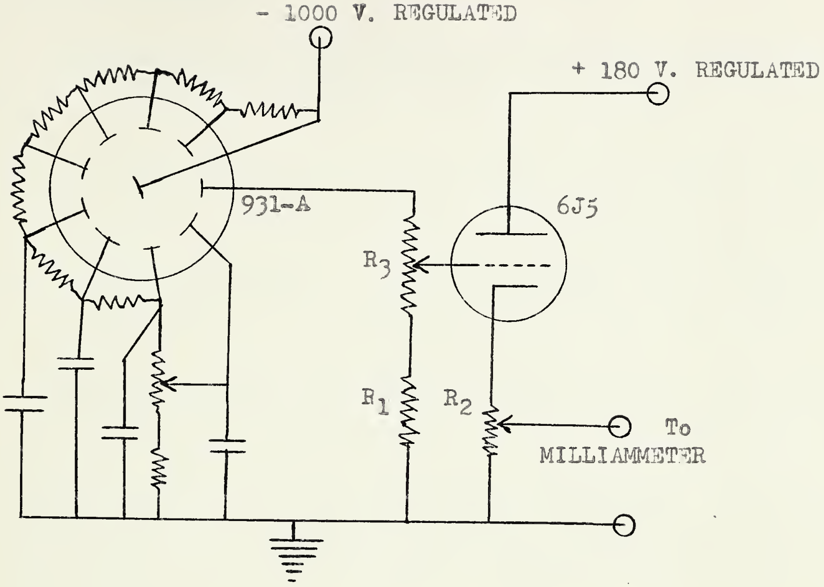


PLATE II The Recording Densitometer.



R1 470,000 ohms
R2 10,000 ohms
R3 10 megohms
unmarked resistors 100K ohms each
all capacitors 0.01 mfd

Figure 1. Photomultiplier Circuit

The plate holder of the densitometer was modified so that it could be rotated a small amount about a vertical axis. Parallel ways with an aluminum carriage to which the plate could be attached were then mounted on the plate holder. This allowed the fringe pattern to be properly aligned in the densitometer, without too much trouble, and once one pattern was aligned the carriage could be advanced

to place any required line in measuring position.

IV EXPERIMENTAL PROCEDURE

1. Vacuum Exposures

With the etalon in place the etalon chamber was flushed twice with air that had been passed over phosphorus pentoxide and anhydrous sodium hydroxide to remove the water vapour and carbon dioxide. Water vapour was further prevented from entering the etalon chamber by a cold trap, cooled with a dry ice-acetone mixture. The cold trap also served to prevent mercury vapour from entering the etalon chamber. After the second flushing the mercury vapour pump was also turned on and the apparatus then left for about two hours to allow the system to reach pressure and temperature equilibrium.

Four exposures were then taken on Eastman IIIF plates (sensitive 6900 A to 2000A) in the following sequence.

1) Neon, visible - for six minutes

2) Mercury, visible - for three hours (four hours for the 1.5 cm. air exposure)

3) Mercury, ultra violet - for one and a half hours (two hours for the 1.5 cm. air exposure)

4) Neon, visible - for six minutes.

The plates were then processed for nine minutes in Eastman D-19 developer and for fifteen to twenty minutes in F - 5 fixer.

The vacuum in the etalon chamber was measured with a MacLeod gauge (see, for instance, 16), usually eight times during the above sequence.

The constant temperature bath was maintained to ± 0.01°, by thermostatic control and was measured by a Beckmann thermometer (for calibration see Appendix IV). To ensure that a representative temperature was used in the calculations, the Beckmann thermometer was read every 15 seconds during two separate temperature cycles of the thermostatic control. The average of these values being taken as the average temperature. There may be a small error in the third decimal place (0.002°C) due to a tendency of the Beckmann to stick slightly.

2. Air Exposures

When the vacuum exposures were completed the etalon chamber was filled with dry, carbon-dioxide-free air at a ~~slight~~ pressure slightly greater than atmospheric, and then allowed to remain overnight before the air exposures were started. The etalon chamber was connected by several feet of heavy walled neoprene tubing to one side of the manometer described by Smith[13]. The other side of the manometer was connected to the vacuum system and maintained at a pressure of the order of 10^{-5} millimeters of mercury by continuous pumping. At this pressure it was unnecessary to make any

correction for the residual pressure on the vacuum side since the air pressure measured by the manometer was accurate only to 10^{-2} millimeters of mercury.

Pressure measurements were made every 15 minutes during an exposure sequence. The room temperature rose steadily, during each exposure, as a result of the heat generated by the UHF oscillator and the mercury vapour pump. This temperature rise expanded the air in the lines and the manometer causing a small pressure rise.

The observed pressures were plotted as a function of time and the pressure for the middle of the neon exposures taken as the average for these exposures. The air pressures for the mercury exposures were taken as being the average of the measured pressures. A correction was then made for the temperature of the steel scale, which is standard at 20 degrees centigrade. A correction was also made to reduce the mercury to standard temperature, zero degrees centigrade, and to reduce the acceleration of gravity to the standard value, 980.665 cm/sec^2, from its value of 981.169 cm/sec^2 at Edmonton. The Barometer temperature correction is:

$$P' = P + P\,(-0.000{,}181{,}86t + 0.000{,}010{,}5(t - 20)\,) \qquad (18)$$

The correction for gravity is:

$$P'' = \frac{P' \times 981.169}{980.665} = 1.000{,}513{,}9P' \qquad (19)$$

V EXPERIMENTAL DATA AND DISCUSSION

The dispersion curve given represents the results of the measurements of the relative refractive index of air at eight wavelengths from 5852 A to 2536 A for each of six air exposures and a like number of vacuum exposures. Two etalon thicknesses were used, a 0.5 cm. etalon and a 1.5 cm. etalon. The data used and values of $(n-1) \times 10^6$ calculated from the data are summarized in table II (0.5 cm. etalon) and table III (1.5 cm. etalon).

A comparison of the refractive indices calculated from the data for the 0.5 cm. etalon with those calculated from the data for the 1.5 cm. etalon (all values reduced to standard air conditions) did not reveal any trend that could be attributed to phase change. Hence it was concluded that any phase change effect was too small to be detected and this was therefore neglected.

An analysis of a few of the densitometer tracings revealed that the fringe patterns were not symmetric but as the asymmetry was not regular it could not be due to non-parallelism of the etalon plates. The asymmetry depended on wavelength but was reasonably constant for the same line on different plates. However, as only a few lines were analyzed no conclusions could be drawn but the indications were that the etalon plates were not sufficiently flat to give symmetry

within the accuracy of measurement.

The fringes were quite sharp in the visible region but became slightly fuzzy in the ultra violet due to the decrease in the reflectivity of aluminum at short wavelengths.

The densitometer apparently gave a faithful reproduction of the fringe pattern but there were indications that if the controls were adjusted to give a very sharp high peak then the recording milliammeter could not follow the pattern rapidly enough and hence distorted the fringe pattern slightly. Some tests were made to determine the effect of this but they were inconclusive. The error apparently was of the same order as the error in measurement, however a fuller investigation might be worthwhile.

The dispersion curve

$$(n-1) \times 10^{-6} = 261.352 + 1.535309\lambda^{-2} + 0.013464\lambda^{-4} \tag{20}$$

was determined by the method of least squares from a weighted average of the observed refractive indices (not corrected to standard air). The values in columns 7, 17, 18, 19, (tables II and III) were weighted one and those in columns 8 and 9 were weighted one-half.

The index of refraction as measured here is only relative and therefore the dispersion curve was adjusted to give a best fit at five points with the dispersion curve found by Barrell and Sears[6]. The modified equation is

$$(n-1) \times 10^6 = 272.315 + 1.599709 \lambda^{-2} + 0.014029 \lambda^{-4} \qquad (21)$$

Equation (21) is for dry, carbon-dioxide-free air and when a correction for the dispersion of 0.03 percent carbon dioxide is made equation (21) becomes the equation for standard air

$$(n-1) \times 10^6 = 272.314 + 1.599{,}975 \lambda^{-2} + 0.014034 \lambda^{-4} \qquad (22)$$

The value of the index of refraction calculated from equation (22) and from the equations found by Barrell and Sears[6], Meggers and Peters[1] and by Edlen[17] are given in table one.

TABLE 1

$(n-1) \times 10^6$ for Standard Air at 760 mm. and 15° C.

Wavelength A	Meggers and Peters	Barrell and Sears	Edlen	Equation (22)
6000	276.33	276.97	276.97	276.87
5000	278.13	278.97	278.96	278.94
4000	281.71	282.74	282.76	282.86
3000	290.69	291.26	291.61	291.82
2000	325.58	319.06	324.08	321.09

The values of the indices calculated by equation (22) are lower than Barrell and Sears[6] in the red and larger in the violet, the greatest deviation being 12 in the last two figures.

The curves cross at approximately 4500 A.

Comparing equation (22) with the dispersion formula found by Meggers and Peters[1] reveals that equation (22) gives larger values for the index at wavelengths greater than approximately 2500 A and smaller values for the shorter wavelengths, being about one percent less at 2000 A.

Edlen[17] had derived an equation based on the works of Barrell and Sears[6], Koch[18], and Traub[19] which crosses the curve given by equation (22) at two points; descending, at approximately 4800 A and ascending, in the region of 2800 A.

Edlen[17] has tested the indices as calculated by his equation using the procedure described by Meggers and Kessler[3] and claims an accuracy of 1 in 100,000,000. The values of the refractive index calculated by equation (22) were checked by the combination principle which indicated an accuracy of 1 in 30,000,000, this is of the same order as the calculated probable error. The combination principle test indicated that the refractive index, as calculated by equation (22), is too low in the ultra violet. The error being about half of the error in Meggers and Peters[1] values and in the opposite direction.

TABLE II

0.5 cm. Etalon

2t = 1.000,697 cm.

	e (Vacuum plates)			e' (Air plates)			$(n - 1) \times 10^6$ using columns			average of columns 8 and 9
							3 and 4	2 and 5	1 and 6	
	1	2	3	4	5	6	7	8	9	10
5852	0.9262	0.9142	0.9044	0.3847	0.5346	0.5068	262.03	270.22	267.89	269.05
5461	0.1516	0.1504	0.1521	0.9631	0.1164	0.0869	262.53	270.99	269.31	270.15
4358	0.0700	0.0494	0.0503	0.1551	0.3539	0.3146	265.88	274.58	271.97	273.27
4047	0.5131	0.5091	0.5096	0.1050	0.3519	0.2864	266.70	276.71	273.90	275.30
3650	0.3774	0.3689	0.3621	0.7550	0.0400	0.9523	269.66	279.81	276.30	278.05
3132	0.0810	0.0682	0.0761	0.8393	0.1178	0.0413	274.23	283.51	280.40	281.95
3125	0.1730	0.1671	0.1566	0.9480	0.2240	0.1707	274.60	282.89	281.04	281.96
2536	0.8979	0.8755	0.8819	0.1017	0.4437	0.3901	284.39	293.22	291.30	292.26

TABLE III

1.5 cm. Etalon

$2t = 3.000,237$

	e (Vacuum Plates)			e' (Air Plates)			$(n - 1) \times 10^6$ using columns			Final average
							13 & 14	12 & 15	11 & 16	
	11	12	13	14	15	16	17	18	~~18~~ 19	20
5852	0.1103	0.1015	0.1123	0.8037	0.7549	0.7006	267.08	266.33	265.10	265.898
5461	0.5490	0.5600	0.5466	0.2781	0.2228	0.1489	268.13	266.88	265.73	266.684
4358	0.6862	0.6840	0.6803	0.3456	0.2839	0.1802	271.14	270.19	268.65	269.826
4047	0.7635	0.7628	0.7555	0.9662	0.8928	0.7830	272.59	271.50	270.01	271.220
3650	0.3524	0.3597	0.3483	0.9422	0.8486	0.7384	274.88	273.60	272.36	273.710
3132	0.0679	0.0754	0.0700	0.8572	0.7386	0.6183	279.59	278.30	277.12	278.328
3125	0.2170	0.1999	0.2073	0.0878	0.9312	0.8349	280.04	278.49	277.31	278.480
2536	0.7015	0.7096	0.6960	0.0359	0.7812	0.6963	290.32	280.05	287.40	288.484

TABLE IV

Pressures and Temperatures

Plate	Temperature degrees Centigrade	Pressure in millimeters of mercury			
		first Neon	Mercury Visible	Mercury Ultra-Violet	second Neon
1	20.220	0.007	0.007	0.007	0.007
2	20.224	0.030	0.030	0.031	0.031
3.	20.222	0.022	0.022	0.023	0.023
4	20.216	724.24	734.76	735.81	735.60
5	20.216	751.66	752.18	753.17	753.29
6	20.219	749.37	748.40	748.40	748.78
11	20.218	0.001	0.001	0.001	0.001
12	20.215	0.006	0.005	0.004	0.003
13	20.219	0.006	0.006	0.006	0.006
14	20.212	750.15	750.56	750.97	750.78
15	20.219	746.18	746.78	746.49	746.59
16	20.217	741.29	741.07	741.53	741.74

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APPENDIX I

The Method of Least Squares

The method of least squares enables an equation of given form to be fitted to a number of data in such a way that the sum of the squares of the departures of the data from the final curve is a minimum. It is treated in books on statistical analysis[11]. A very brief outline of the procedure and equations follows.

The general equation of the form

$$Y = A + BX + CX^2 + \cdots\cdots\cdots \qquad \text{(i)}$$

may be fitted to the k points (X_i, Y_i) by solution of the following equations for the constants A, B, C, ...

$$\begin{array}{rcllll}
\sum_i Y_i & = & Ak & + B \sum_i X_i & + C \sum_i X_i^2 & + \cdots\cdots \\
\sum_i X_i Y_i & = & A \sum_i X_i & + B \sum_i X_i^2 & + C \sum_i X_i^3 & + \cdots\cdots \\
\sum_i X_i^2 Y_i & = & A \sum_i X_i^2 & + B \sum_i X_i^3 & + C \sum_i X_i^4 & + \cdots\cdots \\
\cdots\cdots & & \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots
\end{array} \qquad \text{(ii)}$$

In this case, the quantity $\sum_i (Y_i - Y)^2$ is a minimum where Y is the computed value, and

$$Y_i = A + B X_i + C X_i^2 + \cdots\cdots \qquad \text{(iii)}$$

An estimate of the goodness of fit and the probable error of the final equation is given by

$$\text{Probable error} = 0.6745 \sqrt{\frac{\sum_i (Y_i - Y)^2}{k\,(k - 3)}} \qquad \text{(iv)}$$

while the probable error or deviation of a given point (X_i, Y_i) from

the curve is given by

$$0.6745 \sqrt{\frac{{}_{i}\sum (Y_i - Y)^2}{k}} \qquad (v)$$

The data of these experiments were treated by use of the above equations, where refractive index replaces Y and the inverse square of the wavelength replaces X.

APPENDIX II

MacLeod Gauge

A new, all glass, Macleod gauge was constructed when it was discovered that the one used by Smith[13] gave inconsistent values for the same vacuum.

The accuracy of the capillary was checked, by measuring the length of a drop of mercury as it was moved along the capillary, and should be within one percent. The capillary was also calibrated by filling it with mercury and weighing on a precision balance. Very fine glass fibres were fused to the capillary at two points and relative to the lower of these the measured volume of the capillary is:

Position in mm.	Volume in ml.
- 0.032	0.1823
11.318	0.1720
109.940	0.0831
132.480	0.0601

The upper index is 109.351 mm. above the lower index and the lower index is 200.9 mm. below the outside end of the capillary tube.

The end of the capillary is at 23.5 cm. relative to the scale on the MacLeod gauge or 196.59 mm. above the lower index. However if the mercury is brought to within one centimeter of this point it will probably be necessary to correct

for the volume of the end which is approximately 0.14 ml.

The total volume, V, and the volumes, v, above the first and second indices are respectively: 101.35 ml.: 0.1323 ml. and 0.0818 ml. and the area of the capillary tube is 0.92 mm^2.

APPENDIX III

Hilger El Spectrograph - Horizontal Focus

Due to astigmatism in the spectrograph the focus is not the same for horizontal lines as it is for vertical lines. When using a spectrograph crossed with an interferometer the vertical focus is not very important because the slit width is of the order of one millimeter.

The position of the bright fringes produced by the interferometer must be measured accurately hence it was decided to try to determine what the focus settings would be to give a good focus for horizontal lines. This was accomplished by making a brass slide that could be substituted for the fishtail and then laying a number of very fine glass wires across a window in this slide. When the slide was in position the glass wires were very nearly in contact with the slit and effectively acted as sharp horizontal lines across the slit.

Focus plates were then taken to determine the best focus for horizontal lines, using the settings for vertical focus as a starting position. The focus settings found are given below, for both horizontal and vertical lines.

Range	Prism	Focus	Tilt	Type of Line
2400 - 3400 A	14.95	37 - 7	14.0	horizontal
3400 - 7000 A	18.15	53 -20	6.0	horizontal
2400 - 3400 A	14.95	37 -16	8.2	vertical
3400 - 7000 A	18.15	53 -24.5	2.8	vertical

APPENDIX IV

Calibration of the Beckmann Thermometer

The Beckmann thermometer used by Smith[13] was recalibrated to determine if it had undergone any change in the two years since its previous calibration. The procedure used was identical with that described by Smith[13], Appendix B, and hence will only be briefly outlined here.

The saturated vapour pressure of water which changes approximately 0.01 mm. per 0.01° C. in the region of 20° C. was used to calibrate the Beckmann on the absolute scale. Water, distilled twice in air and once in a vacuum, was vacuum distilled into a bulb which was connected to one side of a U tube (2 cm. diameter tubing). The other side of the U tube was held at vacuum pressure.

The bulb containing the water was immersed in a constant temperature bath with the Beckmann thermometer. The water vapour pressure on one side of the U tube caused a difference in height of the two mercury surfaces which was equal to the water vapour pressure and thus a function of temperature.

The difference in the two mercury levels was measured with a travelling microscope which carried its own parallel light source. The parallel light gave a sharp image of the flat mercury meniscus thus making it easy to measure the difference in the mercury levels to 0.01 mm.

Twelve measurements of the difference in height of the mercury columns were made for each temperature. These were averaged and corrected for the temperature of the mercury columns and the gravitational acceleration at Edmonton.

The observations and results are summarized in a table. Vapour pressures were converted to temperatures using a table in the Handbook of Chemistry and Physics[17]. A straight line was fitted to the data by the method of least squares, giving the following equation:

$$T = 17.235 + 0.944\ B\ (\pm 0.054)$$

where T is the temperature in degrees Centigrade, and B is the reading of the Beckmann thermometer.

Beckmann Reading B	Corrected Difference in Height in mm. of Hg. (vapour pressure)	Temperature in Degree C. T
0.388	15.103	17.611
0.658	15.346	17.864
0.760	15.419	17.939
1.193	15.818	18.348
1.877	16.493	19.016

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